Product Planning & Development (21-423)

Advanced Manufacturing Laboratory
Department of Industrial Engineering
Sharif University of Technology

Session #12

Course Description

- *Instructor*
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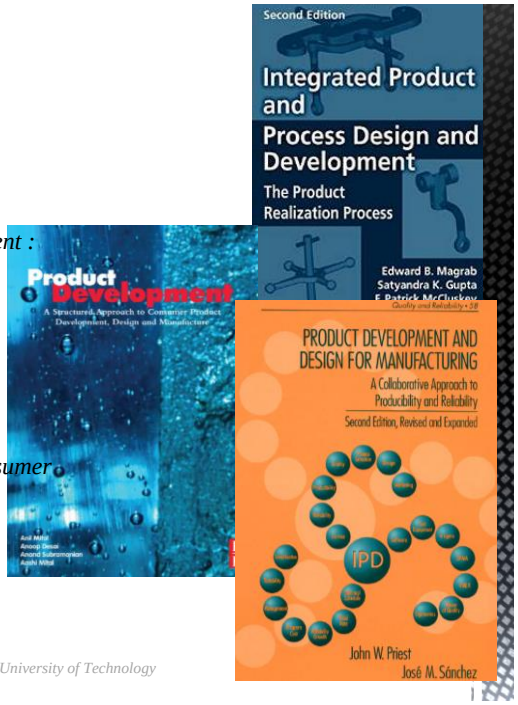
- *Recommended prerequisite*
  - *Manufacturing process I (21-418)*
- *Class time*
  - *Sunday-Tuesday 18:00-19:30*
- *Course evaluation*
  - *Mid-term (25%)*
  - *Final exam (40%)*
  - *Quiz (5%)*
  - *Exercise (Manufacturing Lab.) (30%)*

Session reference

- *Reference:*
  - *Edward B., "Integrated product and process design and development : the product realization process", CRC Press, 2010*
  - *John Priest, Jose Sanchez; "Product Development and Design for Manufacturing: A Collaborative Approach to Producibility and Reliability, Second Edition", CRC Press, 2001*
  - *Mital et al. ,"Product Development A Structured Approach to Consumer Product Development, Design, and Manufacture", Butterworth-Heinemann, 2008*

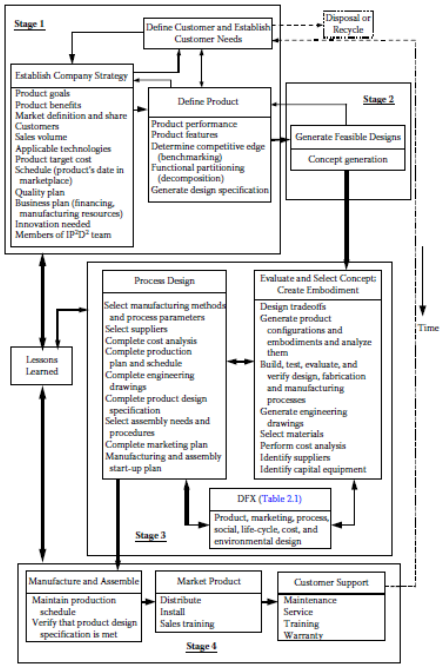


Course Description (Continued..)

- ***Contents:***
- *Product development in the changing Global world*
- *Stages of Product Development*
- *The Structure of the Product Design Process*
- *Early design: Requirement definition and conceptual Design*
- *Trade-off analyses: Optimization using cost and utility Metrics*
- *Detailed design: Analysis and Modeling*
- *Design Review: Designing to Ensure Quality*
- *Production System; Strategies, planning, and methodologies*
- *Production System Development*
- *Planning and Preparation for Efficient Development*
- *Supply chain: Logistics, packaging, supply chain, and the environment*

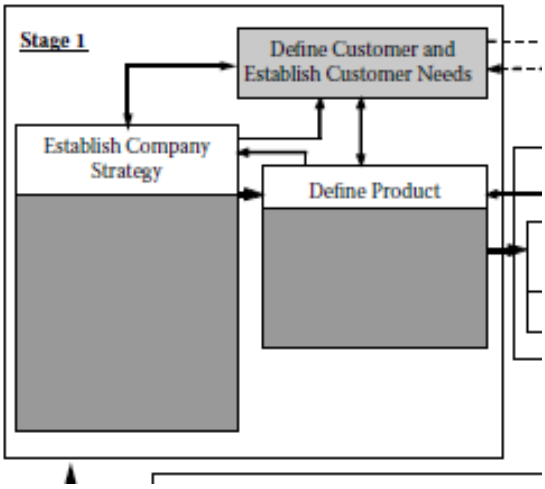
Trade-off analyses: Optimization using cost and

- *Early Design:*



Product Functional Requirements and Functional Decomposition

- *Functional modeling*



Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach*
  - *AD gives a means of clarifying and focusing both the product's functions and the objectives that the design should meet.*
  - *The axiomatic approach provides a compact visual way of expressing the design intent and the overall design objective.*
  - *(FRs) Functional Requirements are defined as the minimum no unique set of independent mandatory requirements that completely characterize the design objectives for a specific need.*
    - *If possible, they must be independent of each other at every level in the design hierarchy.*

Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*

$$\{FR\} = \begin{Bmatrix} (FR)_1 \\ \vdots \\ (FR)_n \end{Bmatrix} \quad \text{and} \quad \{DP\} = \begin{Bmatrix} (DP)_1 \\ \vdots \\ (DP)_n \end{Bmatrix}$$

$$\{FR\} = [A]\{DP\}$$

$$[A] = \begin{bmatrix} A_{11} & A_{12} & \dots & A_{1n} \\ A_{21} & A_{22} & \dots & A_{2n} \\ . & . & \dots & . \\ A_{n1} & A_{n2} & \dots & A_{nn} \end{bmatrix}$$

Product Functional Requirements and Functional Decomposition

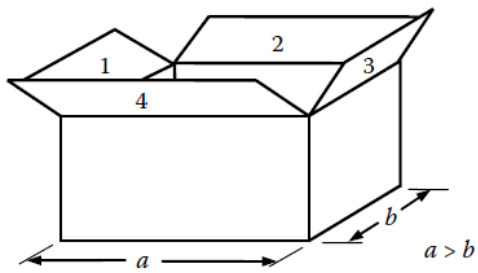
- *Functional Decomposition and the Axiomatic Approach: Two Axioms*
  - *There are three types of solutions to the problem.*
  - *The first type of solution is the one that satisfies Axiom 1 and is attained when [A] is a diagonal matrix. This is called the uncoupled solution*
  - *The second type of solution always violates Axiom 1. In this case and the solution is called coupled*
  - *The third solution is called a decoupled solution, and the independence of the FRs can be assured if we arrange the DPs in a certain order to arrive at the design matrix.*

Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*
  - *Phrasing of the Functional Requirements*
    - *"Tow a disabled automobile from one location to another,"*
    - *"Transport a disabled automobile from one location to another,"*
    - *"Move a disabled automobile from one location to another."*

Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*



Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*
  - *(FR)11 = Place one carton into the system*
  - *(FR)12 = Maintain position of carton*
  - *(FR)13 = Close the carton's flaps*
  - *(FR)14 = Tape carton*
  - *(FR)15 = Release carton*
  - *(FR)16 = Remove sealed box from system*

Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*
  - *(DP)11 = means to place carton into system*
  - *(DP)12 = means to maintain position of carton*
  - *(DP)13 = device to close the carton's flaps*
  - *(DP)14 = taping mechanism*
  - *(DP)15 = means to release carton*
  - *(DP)16 = carton removal device*

Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*

$$\begin{Bmatrix} (FR)_{11} \\ (FR)_{12} \\ (FR)_{13} \\ (FR)_{14} \\ (FR)_{15} \\ (FR)_{16} \end{Bmatrix} = \begin{bmatrix} x & 0 & 0 & 0 & 0 & 0 \\ x & x & 0 & 0 & 0 & 0 \\ x & x & x & 0 & 0 & 0 \\ x & x & x & x & 0 & 0 \\ x & x & x & x & x & 0 \\ x & x & x & x & x & x \end{bmatrix} \begin{Bmatrix} (DP)_{11} \\ (DP)_{12} \\ (DP)_{13} \\ (DP)_{14} \\ (DP)_{15} \\ (DP)_{16} \end{Bmatrix}$$

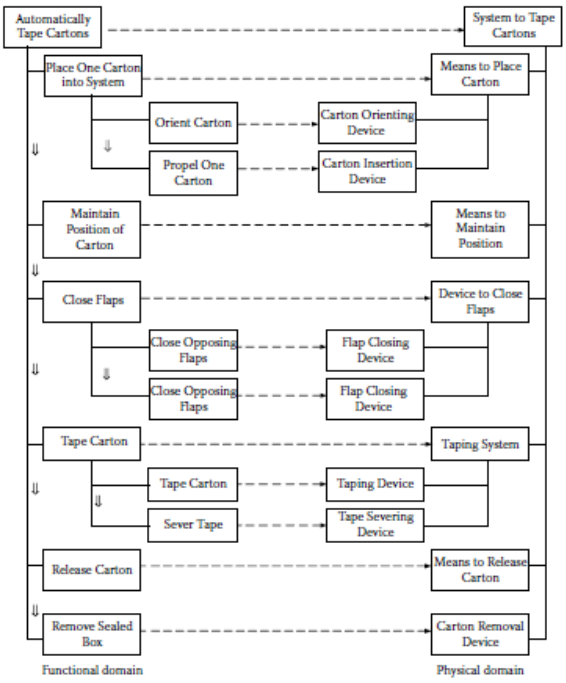
Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*
  - *(FR)111 = Orient carton*
  - *(FR)112 = Propel one carton into the system*
  - *with the corresponding design parameters:*
  - *(DP)111 = Carton orienting device*
  - *(DP)112 = Carton insertion (forward motion) device*

$$\begin{Bmatrix} (FR)_{111} \\ (FR)_{112} \end{Bmatrix} = \begin{bmatrix} x & 0 \\ x & x \end{bmatrix} \begin{Bmatrix} (DP)_{111} \\ (DP)_{112} \end{Bmatrix}$$

Product Functional Requirements

- *Functional Decomposition*
- *and the Axiomatic Approach: Two A*

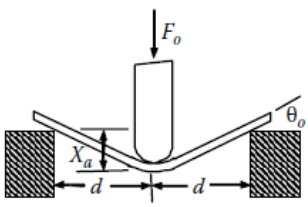


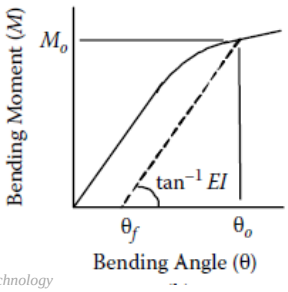
Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*
  - *Intelligent V-Bending Machine*
  - *The objective is to develop a procedure that produces a curved metal part of constant thickness from a thin, flat sheet of metal.*
  - *The generation of the means to satisfy this objective is governed by certain physical laws*
  - *The corresponding DP is a procedure that produces the curved part.*

Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*
  - *Intelligent V-Bending Machine*
  - *FR = Produce a bend angle $\theta f \pm \Delta\theta f$ using sheet metal bending, regardless of how the material and thickness properties vary*
  - *DP = System to generate and control the bend angle*





Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*
  - *Intelligent V-Bending Machine*
  - *The moment Mo is sufficiently high so that it causes the plate to undergo permanent deformation at the corresponding bend angle θo.*
  - *Corresponding to θo is a displacement Xa under the applied force Fo When Mo is released, however, there is a certain amount of spring-back to a bend angle θf < θo.*
  - *Corresponding to θf is a displacement ΔXa, which is the amount of permanent deformation under the point where the force was applied.*
  - *From classical beam/plate theory, it is known that Xa ~ θ ~ F/EI, M ~ F and, therefore, M/θ ~ EI, where E the Young's modulus and I is the moment of inertia of the cross section.*

Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*
  - *Intelligent V-Bending Machine*
  - *For a fixed method of supporting the beam/plate, we have that*

$$M_o = F_o d/2$$

$$\theta_o = \tan^{-1}(X_a/d)$$

$$\theta_f = \tan^{-1}(\Delta X_a/d)$$

If we are able to measure Fo and Xa (and, consequently, ΔXa), then we have a means of controlling the process.

Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*
  - *Intelligent V-Bending Machine*

$$\theta_f = \theta_o - \frac{M_o}{\tan^{-1} EI} = \tan^{-1}(X_a/d) - \frac{F_o d/2}{\tan^{-1} EI}$$

  - *We have three independent parameters:*
    - *Mo, which is proportional to the applied force Fo;*
    - *EI, which is a function of a physical property of the material and the cross-sectional dimensions of the plate; and*
    - *θf, which is the resulting bend angle of the plate after the release of Mo..*

Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*
  - *Intelligent V-Bending Machine*
  - *We have three independent parameters:*
    - *Mo, which is proportional to the applied force Fo;*
    - *EI, which is a function of a physical property of the material and the cross-sectional dimensions of the plate; and*
    - *θf, which is the resulting bend angle of the plate after the release of Mo..*

$$(FR)_1 = M_o \quad \text{(Generate moment)}$$

$$(FR)_2 = \theta_o \quad \text{(Bend and deform metal)}$$

$$(FR)_3 = \theta_f \quad \text{(Release to final bend angle)}$$

Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*
  - *Intelligent V-Bending Machine*
  - *We have three independent parameters:*
    - *Mo, which is proportional to the applied force Fo;*
    - *EI, which is a function of a physical property of the material and the cross-sectional dimensions of the plate; and*
    - *θf, which is the resulting bend angle of the plate after the release of Mo..*

$$\begin{Bmatrix} M_o \\ \theta_o \\ \theta_f \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & -1 \end{bmatrix} \begin{Bmatrix} F_o d/2 \\ \tan^{-1}(X_a/d) \\ F_o d/(2\tan^{-1} EI) \end{Bmatrix}$$

Product Functional Requirements and Functional Decomposition

- *Functional Decomposition and the Axiomatic Approach: Two Axioms*
  - *Intelligent V-Bending Machine*

$$\begin{Bmatrix} M_o \\ \theta_o \\ \theta_f \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & -1 \end{bmatrix} \begin{Bmatrix} F_o d/2 \\ \tan^{-1}(X_a/d) \\ F_o d/(2\tan^{-1} EI) \end{Bmatrix}$$

  - *In order to implement this design equation, the following procedure is employed.*
  - *The punch is brought down and the plate is subjected to a force F' o , which results in a displacement under it of X'a.*
  - *The punch is removed and ΔX'a is measured. From these three measurements, we determine tan−1 EI.*
  - *We now apply a slowly increasing force Fo and continuously monitor Fo and Xa until their values produce the desired θf*

Project

- *Product Functional Requirements*